

Synchrotron Radiation Protection



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8th ASAC meeting for NSLS-II Project
May 10-11, 2011

SRP TF Goals

SRP conditions and requirements will affect:

- **Commissioning**
 - Full Passive Protection at 25 mA
 - Active Interlock ON/OFF
- **Safe Machine Operation**
 - Adequate EPS
 - Response Time
 - Phase Space Operation Window
- **Operation Reliability**
 - Balance between Safety Margin and Reliability

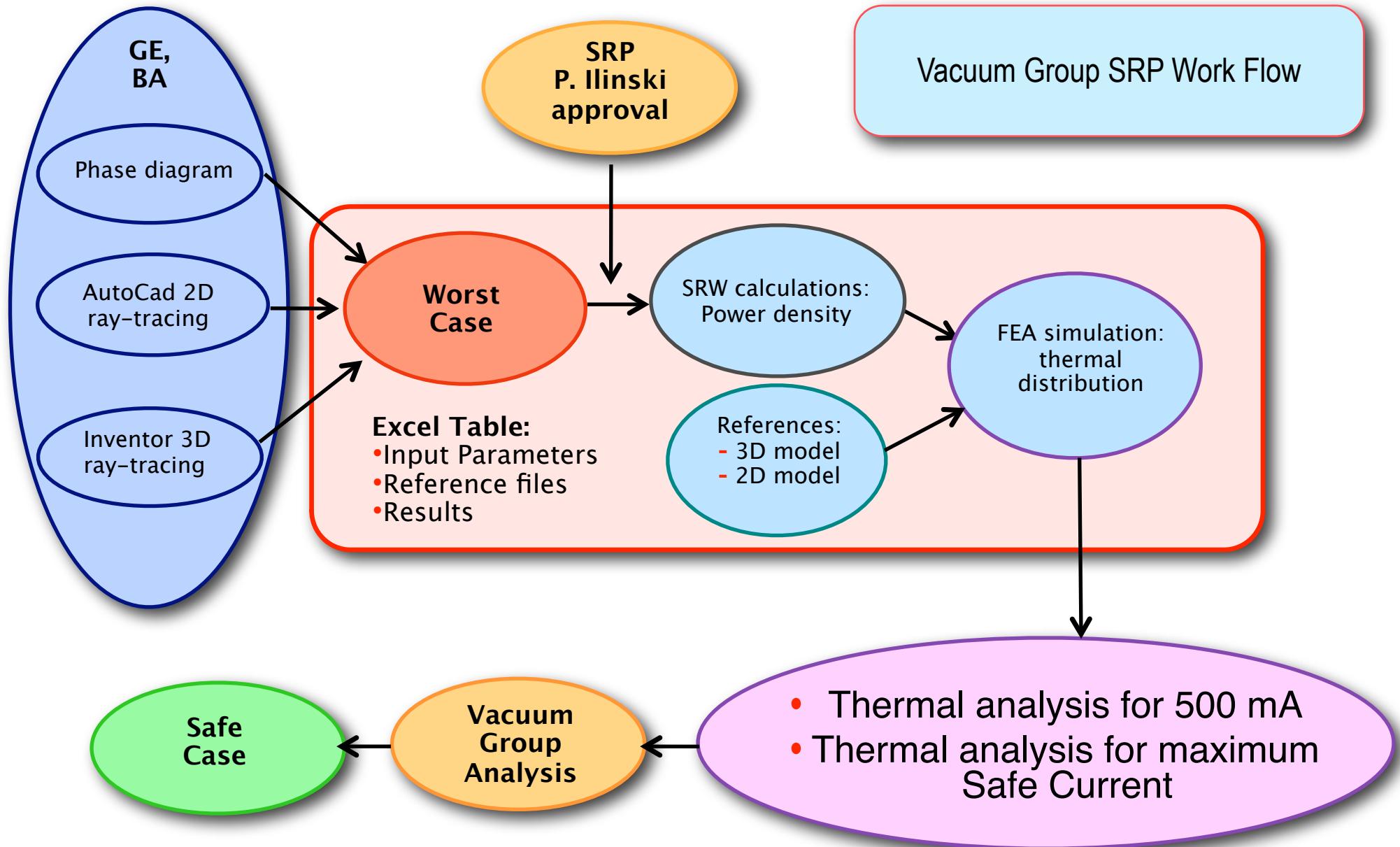
SRP Objectives

- **1. Full Passive Protection from dipole radiation**
 - verifying FPP goals:
 - 25 mA
 - Max. FPP Safe Current
- **2. Active Interlock Envelopes**
 - Insertion Devices
 - Damping Wiggler
 - EPU
 - IVU
 - Dipoles
- **3. Max. Operation Safe Current**
- **4. Max. EPS Response Time**
- **5. Equipment Protection System**
 - Response Time of **1 msec** requires FPGA based EPS

SRP Documentation

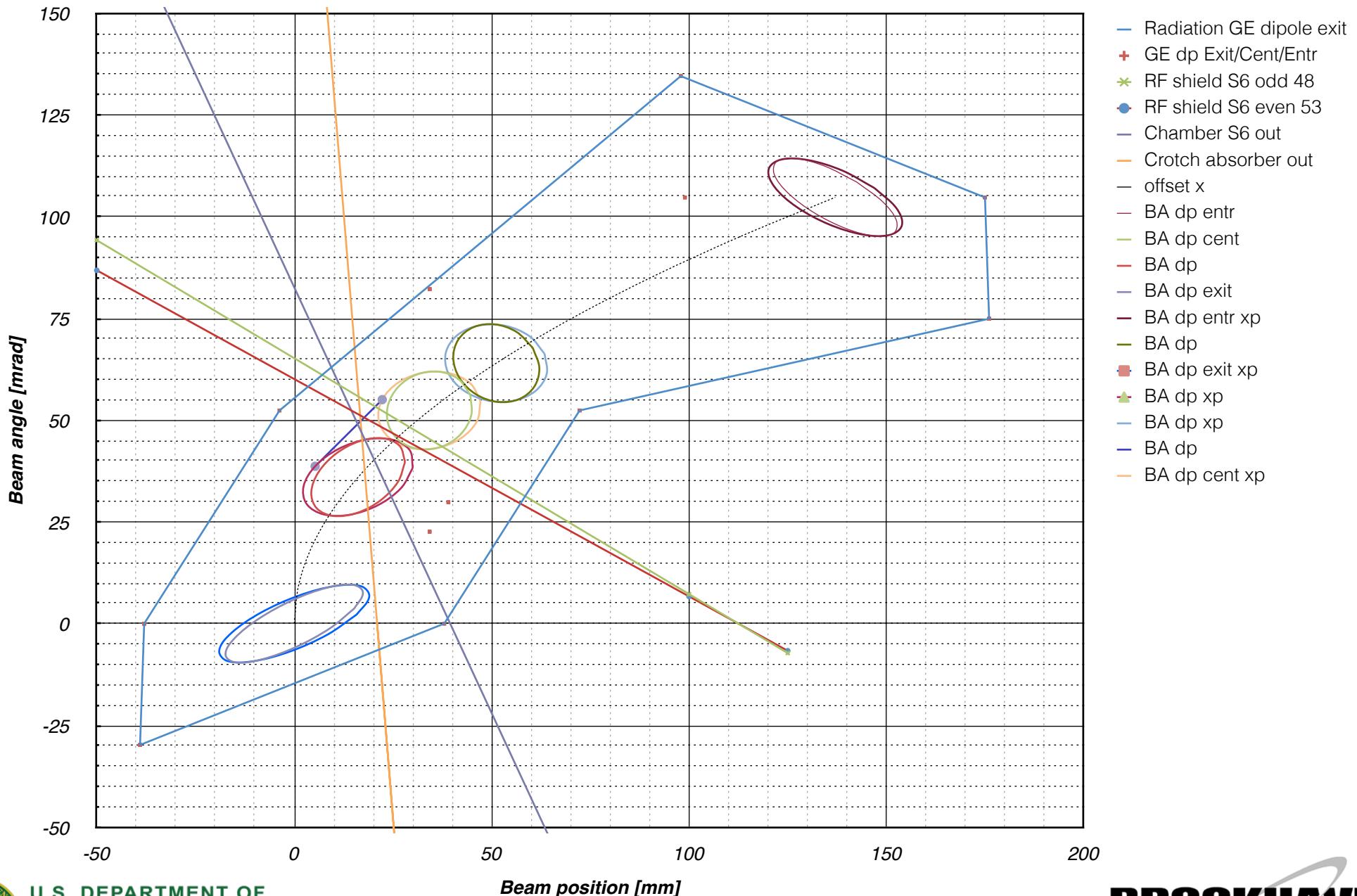
- All Documentation and Results are available at SRP TF SharePoint site: [Documents](#)
- Excel Table for each SRP Case contains all input parameters, list of reference files, main results, and approval status. File originated and maintained by Case Holder (P.Illinski, F.Marcelo)
- Beam Acceptance (I.Pinayev), SRP TF SharePoint
- SRW Power Density results available at LS-XFD1 server (P.Illinski, F.Marcelo, O.Tchubar)
- FEA analysis (V.Ravindranath)
- SRP Technical Notes:
 - P.Illinski, "Defining NSLS-II Active Interlock Envelope", Nov 2010
 - P.Illinski, V. Ravindranath, O. Tchubar, "Active Interlock Envelope for NSLS-II Damping Wiggler", Feb 2011
 - P.Illinski, V.Ravindranath, O.Tchubar, "Maximum Response Time of NSLS-II Active Interlock, Equipment Protection System", Jan 2011
 - I.Pinayev, NSLS-II Beam Acceptance, Apr 2011

SRP Work Flow for Full Passive Protection Cases



Dipole Radiation Phase Space

Horizontal Phase Diagram, Median plane, exit of Dipole 2, even cell



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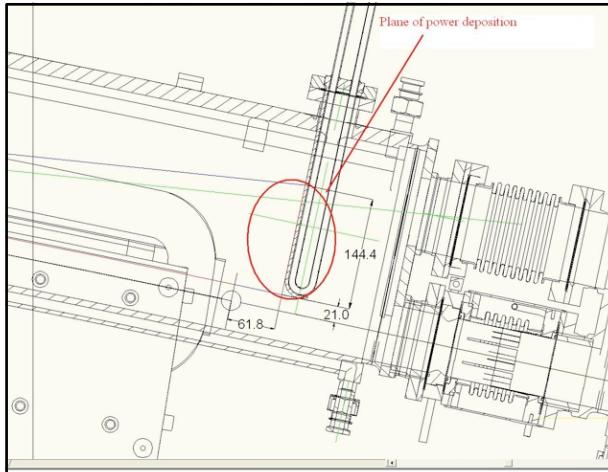
P. Ilinski, NSLS-II SRP, ASAC 05/10/11

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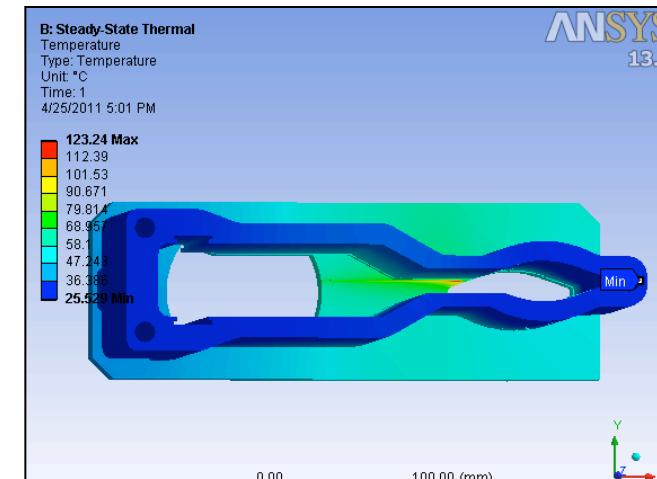
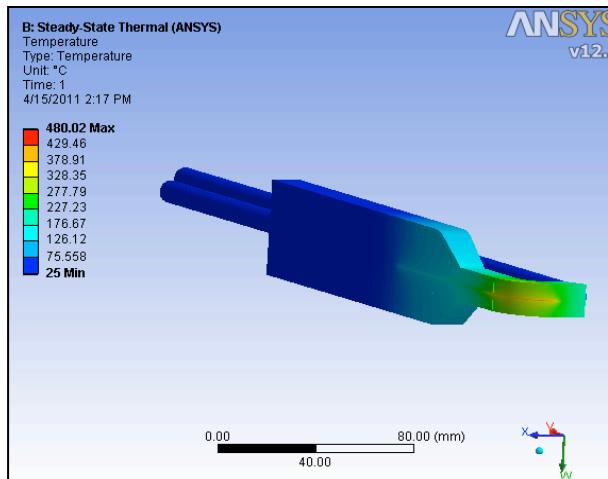
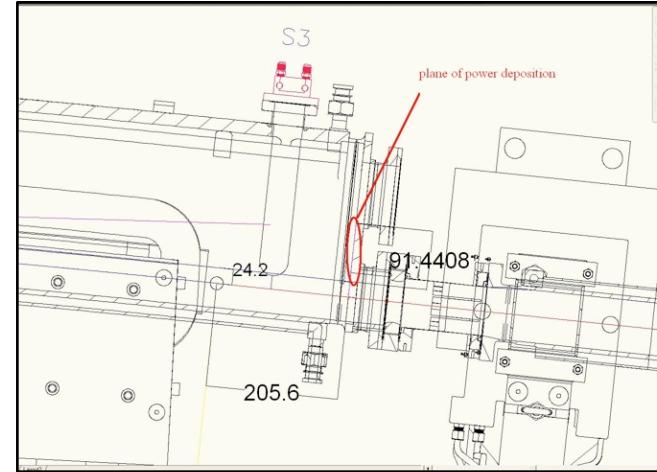
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FPP Cases

Crotch Absorber



Dipole chamber out S3-5 Vert



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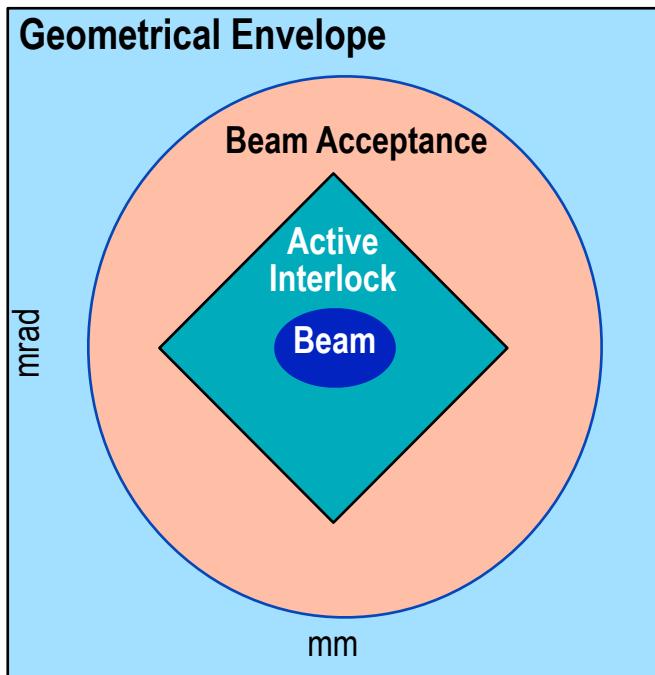
FPP Cases - Safe Current

OSN	Source	Element	Element Position from exit of beam at dipole	Case	e-beam Hor. (offset)	e-beam Vert. (offset)	Max. Power density Visual plane 500 mA	Max. Power density on surface 500 mA	Total power 500 mA	FEA Max. Temp. @ 500mA	FEA Max. Temp. @ Safe Current	Safe Current	Max. power density @ Safe Cond.	Total power @ Safe Cond.
			m	mm	mm	w/mm2			W	C	C	mA	w/mm2	W
GE	Dipole	RF shield S6 center	1.764	Steady	-38	0	0.55		97.7	370	370	500	0.55	97.7
GE	Dipole	crotch center	0.0618	Steady	21	0	6600	860	2348.5	480	207	200	344	940
GE	Dipole	Dipole chamber out S3-5 Vert	0.205	Steady	24.2	7.25	1460	1460	1515.1	988	130	50	146	151
BA	Dipole	Dipole chamber out S3-5 Vert	0.205	Steady	21	7.25	410	410	1328	675	123	70	57.4	185
GE	Dipole	Dipole chamber in S3-5	0	Steady	32	0	<10E-5	<10E-6	<10E-6	Stay Cl.	-	500	-	-
GE	Dipole	crotch cooling vert S3-5	60	Steady	32	0	0	0	0	Stay Cl.	-	500	-	-
GE	Dipole	RF shielded bellows S3-S4 in		Steady										
GE	Dipole	RF shielded bellows S3-S4 out		Steady										
GE	Dipole	Multipole chamber center S4A in		Steady										
GE	Dipole	Multipole chamber center S4A out		Steady										
GE	Dipole	Multipole chamber center S6 in		Steady										
GE	Dipole	Multipole chamber center S6 out		Steady										
GE	Dipole	Flange absorber 21x64 center		Steady										
GE	Dipole	Flange absorber 21x64 vert		Steady										
GE	Dipole	Flange absorber 21x64 vert		Steady										
GE	Dipole	RF shielded bellows S4B-S5A in		Steady										
GE	Dipole	RF shielded bellows S4B-S5A out		Steady										
GE	Dipole	Dipole chamber out Vert		Steady										
GE	Dipole	Dipole chamber vert angle S3-5		Steady										
GE	Dipole	Multipole chamber vert angle S4A		Steady										
GE	Dipole	Multipole chamber vert angle S6		Steady										
GE	Dipole	BPM vert angle S6		Steady										
GE	Dipole	RF shielded bellows vert angle S3-S4		Steady										
GE	Dipole	RF shielded bellows vert angle S4B-S5A		Steady										

FPP cases are identified and treated by
Vacuum Group
Worst FPP Cases are at the top of the list



Defining Active Interlock Envelope for IDs



Geometrical Envelope (GE) - phase space defined by geometrical boundaries of machine elements

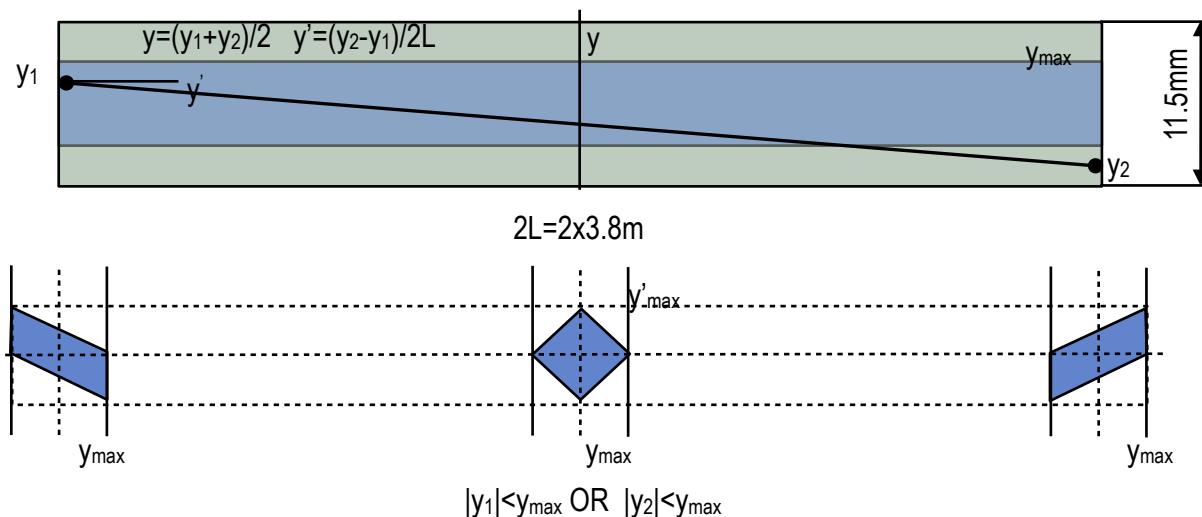
Beam Acceptance (BA) - phase space of all possible e-beam close orbits

Stay Clear Condition - situation when radiation fan does not intercept machine element

Stay Safe Condition - situation when radiation fan intercepts machine element, but satisfies safe steady state operation condition

Active Interlock (AI) Envelope - e-beam phase space, which satisfies Stay Safe or Stay Clear Condition. The electron beam will be dumped once it will get outside the AI Envelope

Operation Reliability ~
(Active Interlock)-(Beam)
(Beam Acceptance)



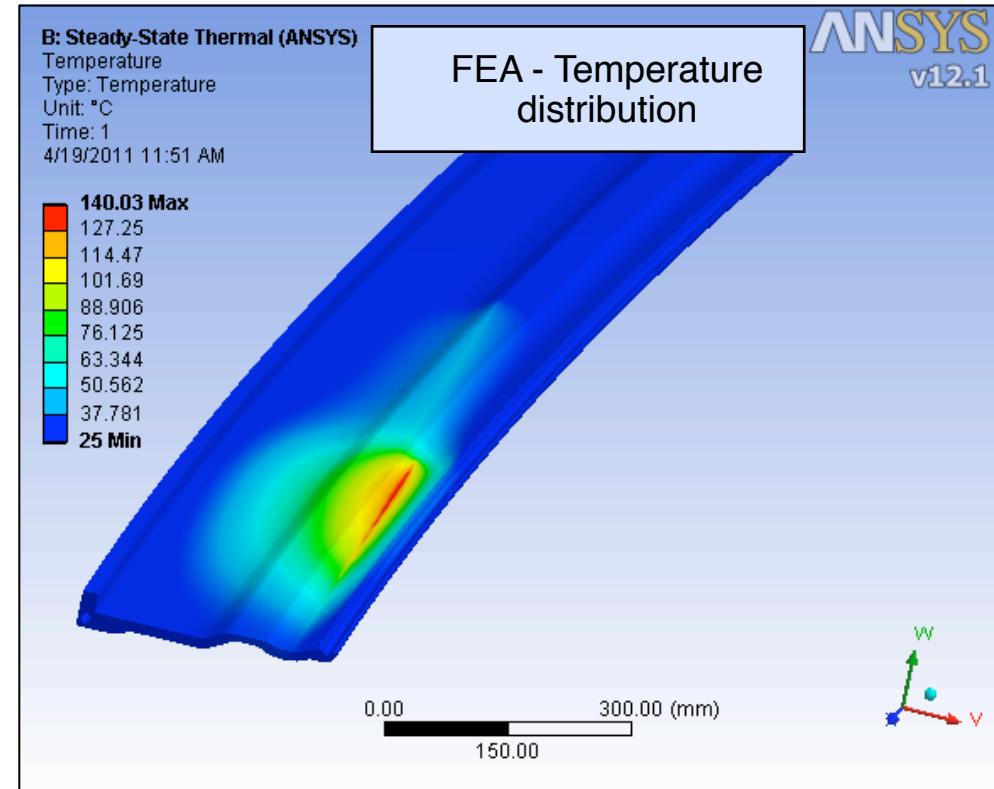
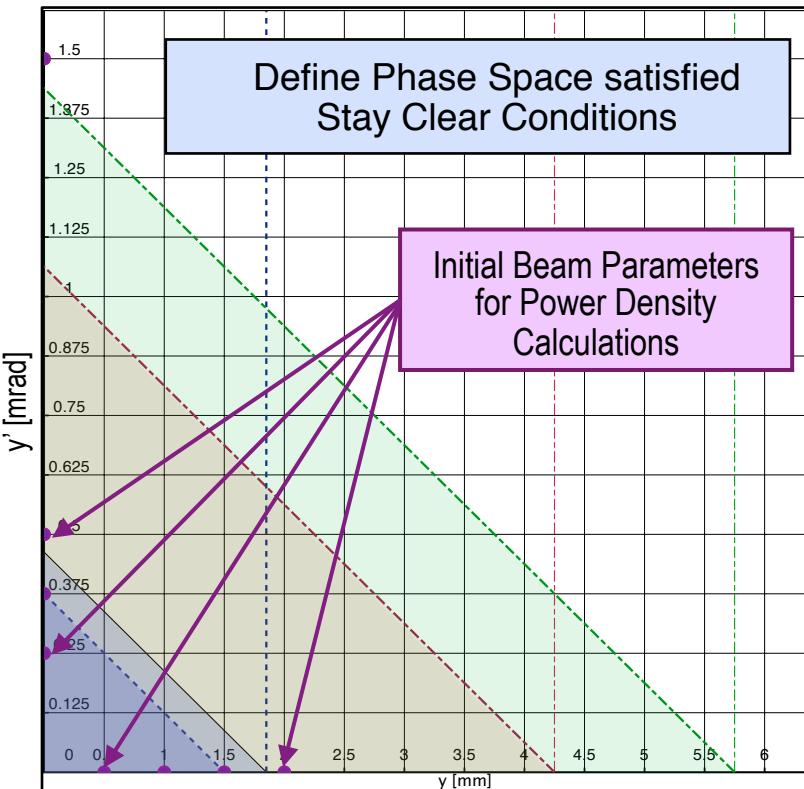
Active Interlock Envelope can be of any shape. Only for “diamond” shape envelope, there is no need to calculate the e-beam trajectory angle



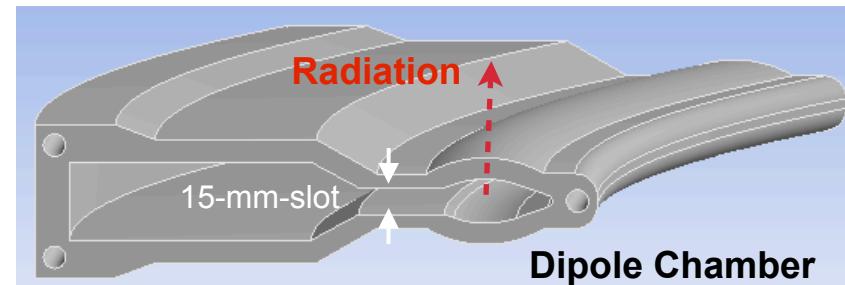
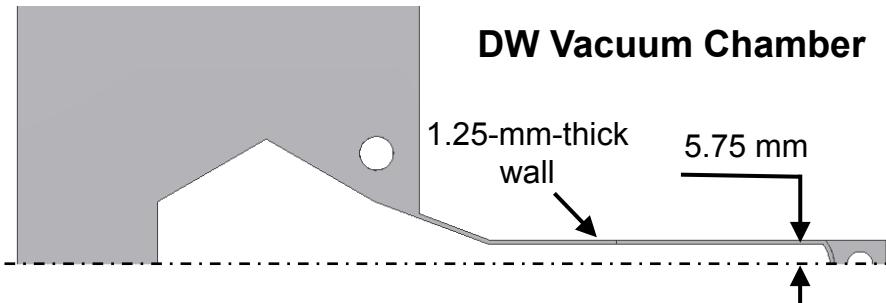
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SRP Work Flow for IDs Active Intelock Cases

- Define the SRP Case (vacuum chamber, dipole chamber, etc)
- Define the Geometrical Envelope for the Case
- Define Phase Space satisfied Stay Clear Condition
- Power Density distributions are calculated with SRW at Phase Space boundaries
- FEA is performed for Power Density distributions to obtain temperature distributions
- Active Interlock Envelope, which satisfied Stay Safe Condition is defined



Active Interlock - IDs (vert.)



						Active Interlock Envelope - Vertical										
						Vacuum Chamber			Dipole Chamber				FE Fixed Mask			
SN	Source	Gap	Bx	Bz	mode	e-beam	Temp	Cond.	e-beam	Temp	Cond.	modif	e-beam			
		mm	T	T		mm	mrad	C	Stay	mm	mrad	C	Stay	15mm vs 21mm	mm	mrad
1	DW100x2	15	1.8	-	-	1.5	0	33	Safe	1.5	0.000	29	Safe	slot	0.5	0.25
2	DW100x2	15	1.8	-	-	0	0.375	39	Safe	0	0.375	79	Safe	slot		
3	IVU20	5	1.03	-	-	?	?	?	?	0	0.5	65	Safe	slot		
4	IVU20	5	1.03	-	-	?	?	?	?	0	0.375	-	Clear	aprt		
5	EPU49x2	min	0.71	0	LV	0.5	0.25	130	X	0	0.375	90	Safe	slot		
6	EPU49x2	min	0.71	0	LV	0.5	0.25	130	X	0	0.375	-	Clear	aprt		
7	EPU49x2	min	0.57	0.57	HE	0.5	0.25	170	X	0	0.25	75	Safe	slot		
8	EPU49x2	min	0.57	0.57	HE	0.5	0.25	170	X	0	0.375	-	Clear	aprt		

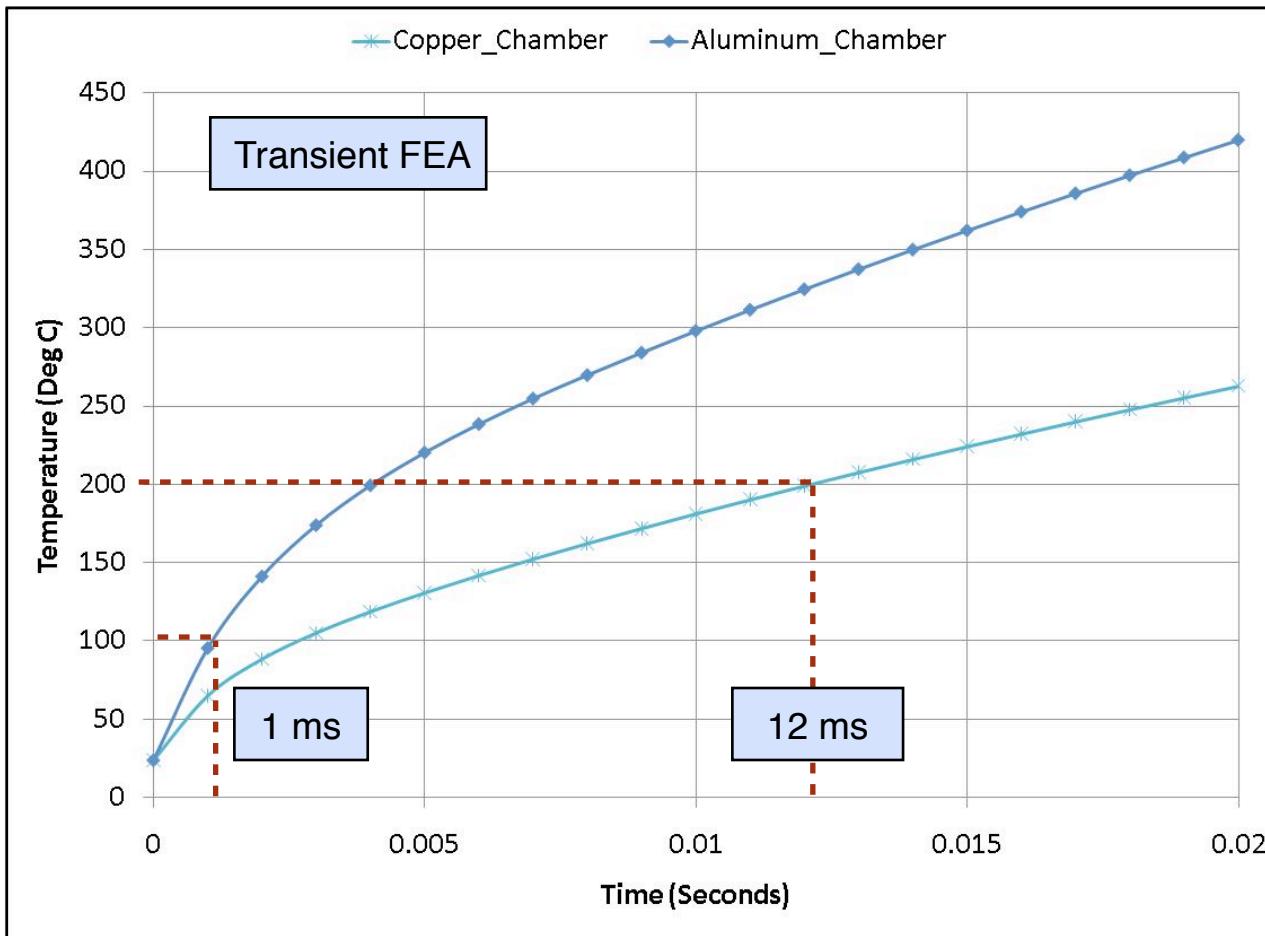
Active Interlock Envelope - IDs (vert.) =
Rectangular shape of [0.5mm,0.25mrad]
will comply with EPS



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Maximum EPS Response Time

WORST CASE = DW radiation hits downstream edge of the DW aluminum vacuum chamber (vertical angle = 1.5 mrad)
Maximum EPS Response Time ~ 1 ms

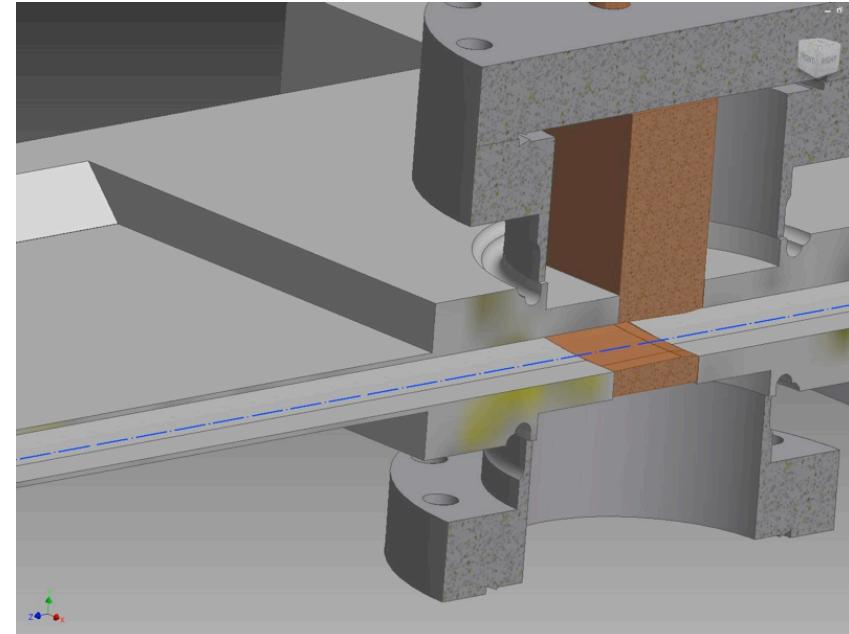
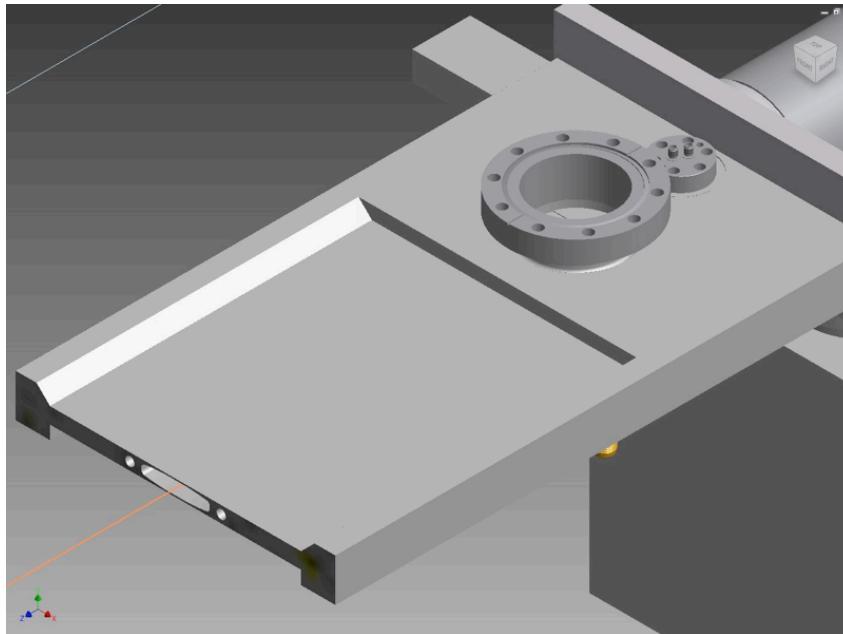


Maximum EPS Response Time - DW Case

The situation can be greatly improved if copper inserts will be installed at the end of the DW vacuum chamber.

Response Time will increase to **~12 msec**

Implemented for new design of DW Vacuum Chamber:



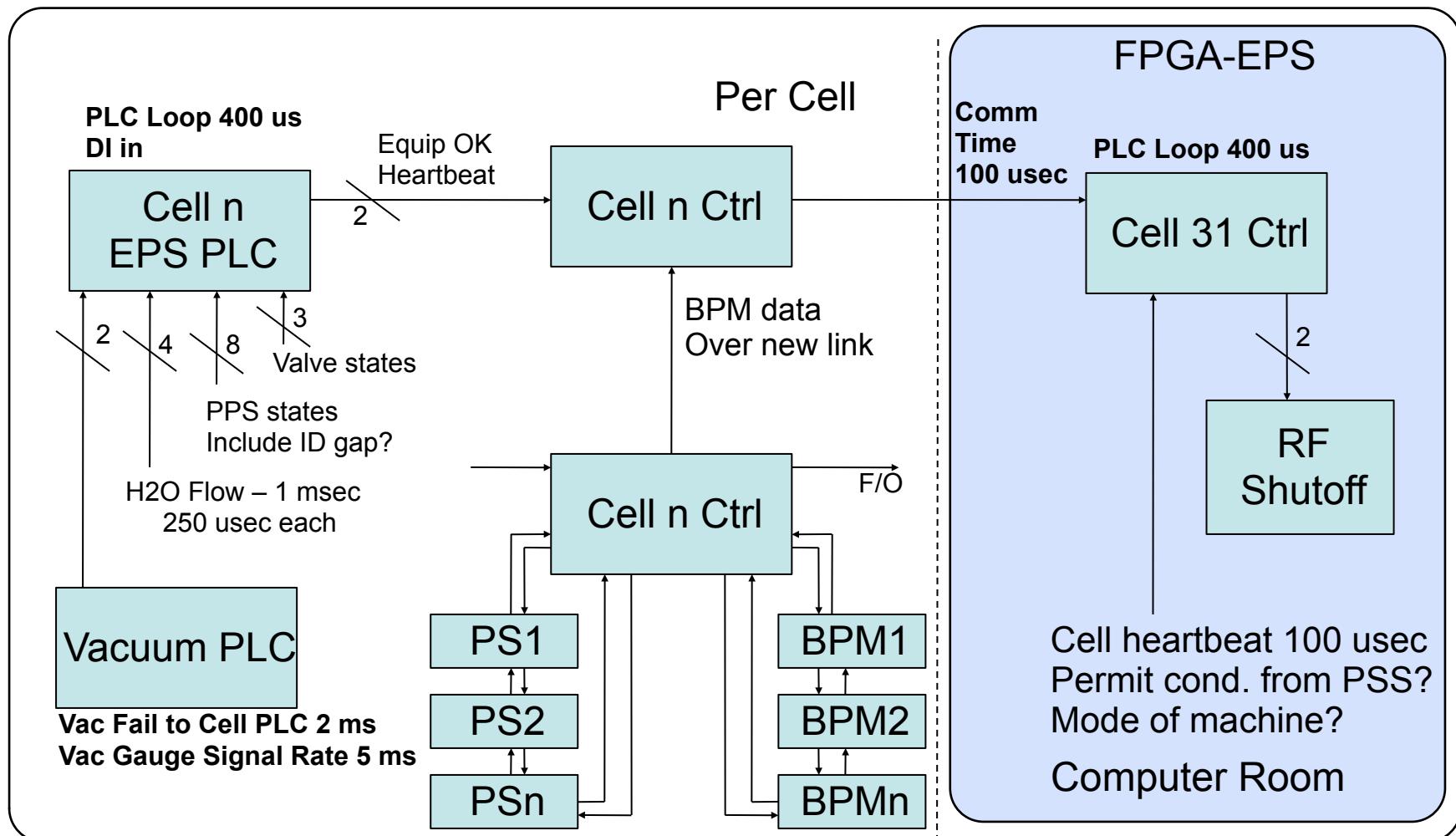
FPGA-based EPS

PLS-based EPS -> Reaction Time = 7ms

FPGA-Based EPS (B. Dalesio) will be part of the Control System

FPGA-Based EPS -> Reaction Time ~ 0.1ms + flexibility

FPGA-Based EPS is in operation at PETRA-III



Summary

- 1. Full Passive Protection for dipole radiation
 - at the moment Safe Current = **50 mA**
- 2. Active Interlock Envelopes
 - Insertion Devices
 - **[0.5 mm, 0.25 mrad]**
- 3. Max. Operation Safe Current
 - Safe Current = **2 mA (DW Vac. Chamber)**
- 4. Max. EPS Response Time
 - Max. Response Time = **1 msec (DW Vac. Chamber)**
 - Effort to improve Max. Response Time
- 5. Equipment Protection System
 - FPGA based EPS with Response Time **< 1 msec** is under development

Supplemental

Detailed Results for Defining IDs Active Interlock Envelopes

Active Interlock (vert.) - Damping Wiggler

SNO	Source	Element	Element Position from cent.str. sect.	Element Length	Element misalignment [upstr.]	Element misalignment [downstr.]	Case	FEA RESULT				
								e-Beam [Transl]	e-Beam [Angle]	Peak Temp.		
			mm	m	mm	mm	mrad	Deg C	W/mm^2	W		
1	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	0.5	0	28	1.1E-03	40
2	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	1	0	30	1.8E-03	68
3	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	1.5	0	33	3.2E-03	124
4	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	2	0	41	6.2E-03	245
5	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	0	0.25	32	2.4E-03	65
6	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	0	0.375	39	5.0E-03	113
7	DW100x2	DW vac. chamber	0	7.6	-1.5	-1.5	Steady	0	0.5	56	1.2E-02	212
1	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	0.5	0.000	27	1.2E-03	96
2	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	1	0.000	28	1.7E-03	132
3	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	1.5	0.000	29	2.3E-03	187
4	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	2	0.000	30	3.3E-03	270
5	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	0	0.125	29	2.6E-03	191
6	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	0	0.250	38	9.6E-03	619
7	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	0	0.375	79	4.5E-02	2519
8	DW100x2	DW dipl. chamber	9.365	2.17	-1.5	-1.5	Steady	0	0.500	272	2.2E-01	11802

Active Interlock Envelope - Damping Wiggler DW100x2 (vert.)

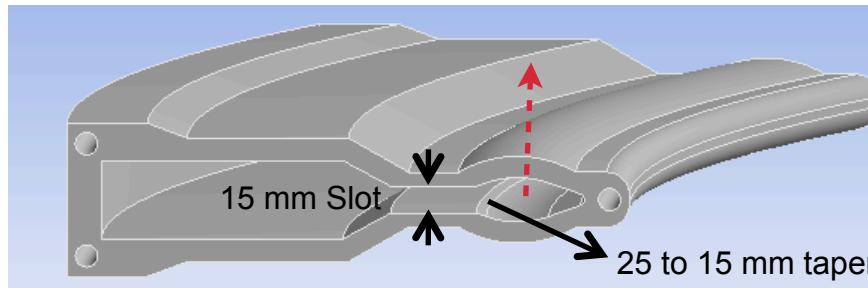
[1.5mm,0mrad]&[0mm,0.375mrad] satisfies

- Stay Clear Condition for DW Vacuum Chamber
- Stay Safe Condition for Dipole Chamber downstream DW



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Active Interlock (vert.) - IVU20 Dipole chamber



The radiation power is deposited on the following two surfaces:

- 15-mm-slot of the dipole chamber
- 25 to 15 mm taper of the dipole chamber

OSN	Str. Sect	e-beam	Source	B	u20 gap	Periods	Source position [from cent.str. sect.]	Visualization Element Dipole Chamber	Case	Beam [Vert. Position, cent. str. sect.]	Beam [Vert. Angle, cent. str. sect]	Peak Temp.	Total power at Visual Plane	Total Power	Max. power density 500 mA
	m			T	mm		m			mm	mrad	Deg. C	W		W/mm ²
2	6.6	lb	u20	1.03	5	148.5	0	15-mm slot	Steady	0	0.25	27	25	57	5.3E-03
6	6.6	lb	u20	1.03	5	148.5	0	25 to 15 mm taper	Steady	0	0.25		32		2.0E-02
3	6.6	lb	u20	1.03	5	148.5	0	15-mm slot	Steady	0	0.375	35	97	188	2.4E-02
7	6.6	lb	u20	1.03	5	148.5	0	25 to 15 mm taper	Steady	0	0.375		91		9.5E-02
4	6.6	lb	u20	1.03	5	148.5	0	15-mm slot	Steady	0	0.5	65	472	804	1.4E-01
8	6.6	lb	u20	1.03	5	148.5	0	25 to 15 mm taper	Steady	0	0.5		332		4.8E-01
5	6.6	lb	u20	1.03	5	148.5	0	15-mm slot	Steady	0	0.7	409	2751	6220	7.0E-01
9	6.6	lb	u20	1.03	5	148.5	0	25 to 15 mm taper	Steady	0	0.7		3469		4.9E+00

Active Interlock Envelope - IVU20 (vert.) Dipole Chamber

[0mm,0.375mrad] satisfies

- Stay Safe Condition for Dipole Chamber with 15-mm-slot
- Stay Clear Condition for Dipole Chamber with 21-mm-diam aperture



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Active Interlock (vert.) - EPU49x2 Dipole chamber

FEA CASES	OSN	Str. Sect	e-beam beta	Source	Bx	Bz	mode	Periods	Src pos. from cent.str .sec.	Visualization Element Dipole Camber	Case	Beam [Transl ation]	Beam [Angle] cent. of str.sect	Peak Temp.	Total power	Total Power (FEA)	Max. power density 500 mA
		m		T	T				m			mm	mrad	Deg. C	W	W	W/mm2
1	3	6.6	lb	eu49x2	0.71	0	LV	38x2	0	15-mm slot	Steady	0	0.25	55	181	450	1.1E-01
	8	6.6	lb	eu49x2	0.71	0	LV	38x2	0	25 to 15 mm taper	Steady	0	0.25		258		6.2E-01
2	4	6.6	lb	eu49x2	0.71	0	LV	38x2	0	15-mm slot	Steady	0	0.375	90	314	1020	2.0E-01
	9	6.6	lb	eu49x2	0.71	0	LV	38x2	0	25 to 15 mm taper	Steady	0	0.375		692		1.4E+00
3	5	6.6	lb	eu49x2	0.71	0	LV	38x2	0	15-mm slot	Steady	0	0.5	118	379	1740	2.5E-01
	10	6.6	lb	eu49x2	0.71	0	LV	38x2	0	25 to 15 mm taper	Steady	0	0.5		1340		1.8E+00
1	14	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	15-mm slot	Steady	0	0.25	75	317	797	7.6E-02
	20	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	25 to 15 mm taper	Steady	0	0.25		475		4.9E-01
2	15	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	15-mm slot	Steady	0	0.375	125	505	1740	1.1E-01
	21	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	25 to 15 mm taper	Steady	0	0.375		1216		7.4E-01
3	16	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	15-mm slot	Steady	0	0.5	152	441	2647	1.0E-01
	22	6.6	lb	eu49x2	0.57	0.57	HE	38x2	0	25 to 15 mm taper	Steady	0	0.5		2170		7.9E-01

Active Interlock Envelope - EPU49x2 (vert.) Dipole Chamber [0mm,0.25mrad] satisfies

- Stay Safe Condition for Dipole Chamber with 15-mm-slot
- Stay Clear Condition for Dipole Chamber with 21-mm-diam aperture

Active Interlock (vert.) - EPU49x2 Vacuum chamber

Polarizat.	Gap	E[eV]	Nund	Off.[mm]	Power[W]	Tmax[deg.C]
Helical	min	220	2	1.5	580	128.5
Helical	min	220	2	2	1240	169.5
Helical	min	220	1	2	140	?
Helical	>min	270	2	2	860	136
Helical	>min	350	2	2	520	?
Helical	>min	400	2	2	380	92.8
Lin.Ver.	min	270	2	1.5	330	89.5
Lin.Ver.	min	270	2	2	770	128.6
Lin.Ver.	min	270	1	2	80	?
Lin.Ver.	>min	350	2	2	480	?
Lin.Ver.	>min	400	2	2	360	87.1
Lin.45	min	380	2	1.5	54	?
Lin.45	min	380	2	2	235	?
Lin.Hor.	min	165	2	1.5	53	?
Lin.Hor.	min	165	2	2	207	?

Active Interlock Envelope - EPU49x2 (vert.) Vacuum Chamber
[0.5mm,0.25mrad] do not satisfies
All EPU49x2 Operation Modes